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The Performance of Small Support Spatial and Temporal Filters for Dim Point Target Detection in IR Image Sequences

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ABSTRACT

The effectiveness of small support spatial filters based on mean, median and morphological opening for the detection of scintillating ultra-dim stationary point targets in IR image sequences has been investigated. The effectiveness of two temporal filters was also studied. The filters were applied to two IR image sequences; an aircraft approaching in an uncluttered background, and an aircraft receding in a bright cloudy background. The spatial filters were effective in detecting the target in the benign background, but neither the spatial nor one of the temporal filters were effective in the cluttered environment. A combination of absolute frame differencing and small support spatial filtering to correct for sensor motion was found to give sufficient increase in signal to clutter ratio to allow detection.

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Executive Summary

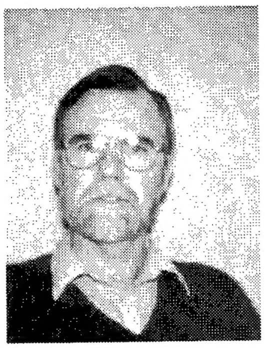
Infrared search and track (IRST) systems are being developed to detect anti-ship sea-skimming missiles at maximum possible range. The problem is essentially the detection of ultra-dim, stationary, point-like targets in clutter in sequences of infrared (IR) images. This paper considers the worst case when the background consists of low sunlit clouds where the brightness range is very large and cloud edges would provide many artefacts which could be considered as possible targets.

The detection of ultra-dim targets poses greater difficulties than the detection of brighter targets. A common method of target detection based on small size spatial filters works by predicting the background by some type of smoothing operation, then subtracting the predicted background from the original image. The aim is to fit the predicted background as closely as possible in the original image without diminishing the target signal. Linear adaptive matched filters can also enhance the response to the target. There is a problem with all spatial filters for detection of ultra-dim point targets with single pixel features in strong clutter because there is no spatial information in a single pixel to allow discrimination from clutter.

If the target is moving, filters based on the temporal profile of the target as it moves through a pixel can be used. The target for IRST has been assumed to be stationary, so these temporal filters cannot be used. However, the average brightness of the target is expected to increase over time as it approaches the sensor. In the short time frame there will be considerable variation in brightness due to scintillation. These temporal behaviours may be able to be exploited for target detection.

The threat posed by anti-ship missiles is of very short duration, and requires response in shortest possible time. Future staring IRST sensor frame rates are expected to be of the order of 25-50 frames/s, and so the images must be processed in very short times. Hence is essential that detection algorithms have low computational load. The operation of the sensor at high frame rates allows the fact that the target is scintillating to be exploited to improve detectability. Absolute frame differencing would suppress the relatively constant background and highlight the rapid fluctuations in the target brightness cause by scintillation. However, sensor jitter would also produce clutter in the high brightness regions in the image. A combination of absolute frame differencing and small support spatial filtering to correct for sensor motion was found to give sufficient increase in signal to clutter ratio to allow timely detection.

Author



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Before joining DSTO in 1968, Bob Warren undertook research in the fields of X-ray and neutron diffraction and X-ray spectroscopy. At DSTO Salisbury he studied the mechanical properties of composite and nitrocellulose propellants, and he made significant contributions to the understanding of molecular relaxations in nitrocellulose. After a 2 year attachment in the UK, he made a number of discoveries in the rheology of nitrocellulose propellants. After working on the modelling and measurement of IR emissions from rocket exhaust plumes, he is now conducting research into the improvement of the performance of IR search and track systems.

Contents

1. Introduction

Infrared search and track (IRST) systems are being developed to detect anti-ship sea-skimming missiles at maximum possible range. Ideally detection would occur as soon as the missile appeared over the horizon. The extreme range of the target means that the missile target would be sub-pixel in size and its angular motion would be very small, and it will be assumed to be zero. The problem is essentially the detection of ultra-dim, stationary, pointlike targets in clutter in sequences of infrared (IR) images. The case where the background is relatively benign, such as clear sky or very light diffuse clouds, has been treated previously[1]. This paper considers the worst case when the background consists of low sunlit clouds where the brightness range is very large and cloud edges would provide many artefacts which could be considered as possible targets.

The detection of ultra-dim targets poses considerably greater difficulties than the detection of brighter targets. "Dim" will be taken to mean low contrast with the background, whether positive or negative. For the case of relatively bright targets in cluttered backgrounds, linear spatial filters are able to decrease the magnitude of the correlated clutter, and increase the response to a target. However, these filters would have a large computational load, and may not be practical for operation at the frame rate of an IRST system. Simpler filters, including nonlinear filters, may give comparable results with a lower computational load. There is a problem with all spatial filters for detection of ultra-dim point targets in strong clutter with single pixel features because there is no spatial information in a single pixel to allow discrimination from clutter. If the target is moving, filters based on the temporal profile of the target as it moves through a pixel can be used. The target for IRST has been assumed to be stationary, so these temporal filters cannot be used. However, the average brightness of the target is expected to increase over time as it approaches the sensor. In the short time frame there will be considerable variation in brightness due to scintillation. These temporal behaviours may be able to be exploited for target detection.

The resolution of the sensor has several effects on detectability of dim point targets. At maximum range a sea-skimming missile would be smaller than the pixel size of practical IRST sensors, so the signal from the pixel containing the target would have a component from the target and a component from the background. Increasing the resolution would have both positive and negative effects. The target pixel at higher resolutions would have a greater contribution from the signal from the target, increasing its effective brightness. Increased resolution would also aid the spatial separation of the target and background. However if temporal filtering is used, increased spatial resolution increases the effect of errors caused by frame misregistration due to sensor motion

The threat posed by anti-ship missiles is of very short duration, and requires response in shortest possible time. Future staring IRST sensor frame rates are expected to be of

the order of 25-50 frames/s, and so the images must be processed in very short times. Hence is essential that detection algorithms have low computational load.

There have been many approaches to the problem of detection of dim point targets. There are a number of linear adaptive spatial filters such as that of Soni et al [2], but they are computationally intensive for non-stationary clutter. Three dimensional spatial-temporal adaptive filters have been described by Melendez and Modestino [3]. A method involving adaptive thresholding of point intensity contrast from surrounding 8 pixels and accumulating results over 95 frames was proposed by New et al [4]. Stationary targets were not considered. Developments of this method were given by Ronda et al [5, 6]. Li and Shen [7] used a frame summing after registration to detect moving targets. A method for clutter suppression using simultaneous adaptive spatial-temporal filtering and jitter compensation has been described by Tartakovsky and Blazek [8], but it appears to be computationally intensive.

There have been a number of cases of the application of temporal filters to dim point target detection. Tzannes and Brooks [9] consider the temporal profile of targets and background as they pass through a pixel location to detect moving targets. Yang et. al. [10] used a combination of positive frame differencing and temporal averaging of the frame difference to detect moving targets with velocities less than 0.3 pixels/frame.

Spatial filtering based on horizontal and vertical morphological opening was used by Zhu et al [11] for small target detection. Max/mean and max/median filters have been used by Deshpande et al [12] for moving point target detection.

None of the filters considered above appear to be ideal for the detection of ultra-dim scintillating targets in heavy clutter at video frame rates. This paper will examine the effect of several spatial and temporal filters and show that separately they are not able to provide sufficient detection capability, but it will be suggested that a suitable combination of spatial and temporal filters could provide acceptable performance.

2. Experimental

Two sequences of IR images will be examined in this work. Both involve an aircraft flying over Gulf St Vincent off Adelaide at an altitude of approximately 30 m. The effective target was the surface of the exhaust pipes of the aircraft. The image sequences were obtained using an Amber Galileo midwave infrared camera. The Galileo focal plane array is 256x256 pixels, each pixel 30 μ on side. The Galileo was fitted with a 300 mm catadioptric lens and operated at 25 frames/s. The 300 mm lens gives a pixel size, or instantaneous field of view (IFOV), of 0.1 mrad. The field of view (FOV) was 1.467°.

The Gabriel software (Aspect Computing, Adelaide, Australia) was used to display image sequences, and also to measure pixel intensities, and means and standard

deviations of image areas. Image filtering and processing were done with specially written C programs.

The Sequence 1 is the aircraft flying towards the sensor with a background of very diffuse high level clouds. The resolution of the original image sequence was 0.1 mrad, which was higher than the resolution desired for the application for which the data was originally collected. The resolution was reduced by resampling with the average of 2x2 pixels of the original image. Because the aircraft did not fly a straight course, there was a drift in bearing during the flight and the target image moved over a small number of pixels, which is contrary to the assumption made for a stationary target in a real IRST. An apparently stationary target location was produced using the following procedure. The target was manually tracked during the periods when it was visible. The values of the target pixel and a small surrounding area were copied to a fixed location using knowledge of the true track. The local mean around the target location and the local mean at the fixed location were calculated, and the copied values were adjusted to allow for the difference in means. The intensity at the old target location replaced with the average local intensity. The final frame of the sequence is shown in Figure 1.

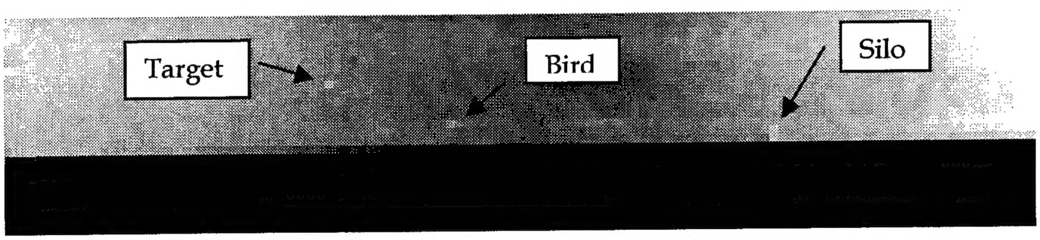

Figure 1 Final frame of modified Sequence 1.

The Sequence 2 is an aircraft flying away from the sensor. It has a small but significant angular velocity, and the target appears to go in and out of clear and cloud regions. The resolution of the image sequence was 0.1 mrad. A second sequence was produced by resampling with the average of 2x2 pixels of the original image. Images from both sequences will be used in this paper. Frame number 1788 of the full resolution sequence is shown in figure 2. The isolated black and white points are defective pixels. The target is not visible in this Figure, so an enlarged portion containing the target is given in Figure 3. The target is the brightest occurrence in a sequence of about 10 frames about frame 1788, when the target can be distinguished from the clouds.

3. Performance of Small Size Spatial Filters

A common method of target detection based on small size spatial filters works by predicting the background by some type of smoothing operation, then subtracting the predicted background from the original image. The aim is to fit the predicted

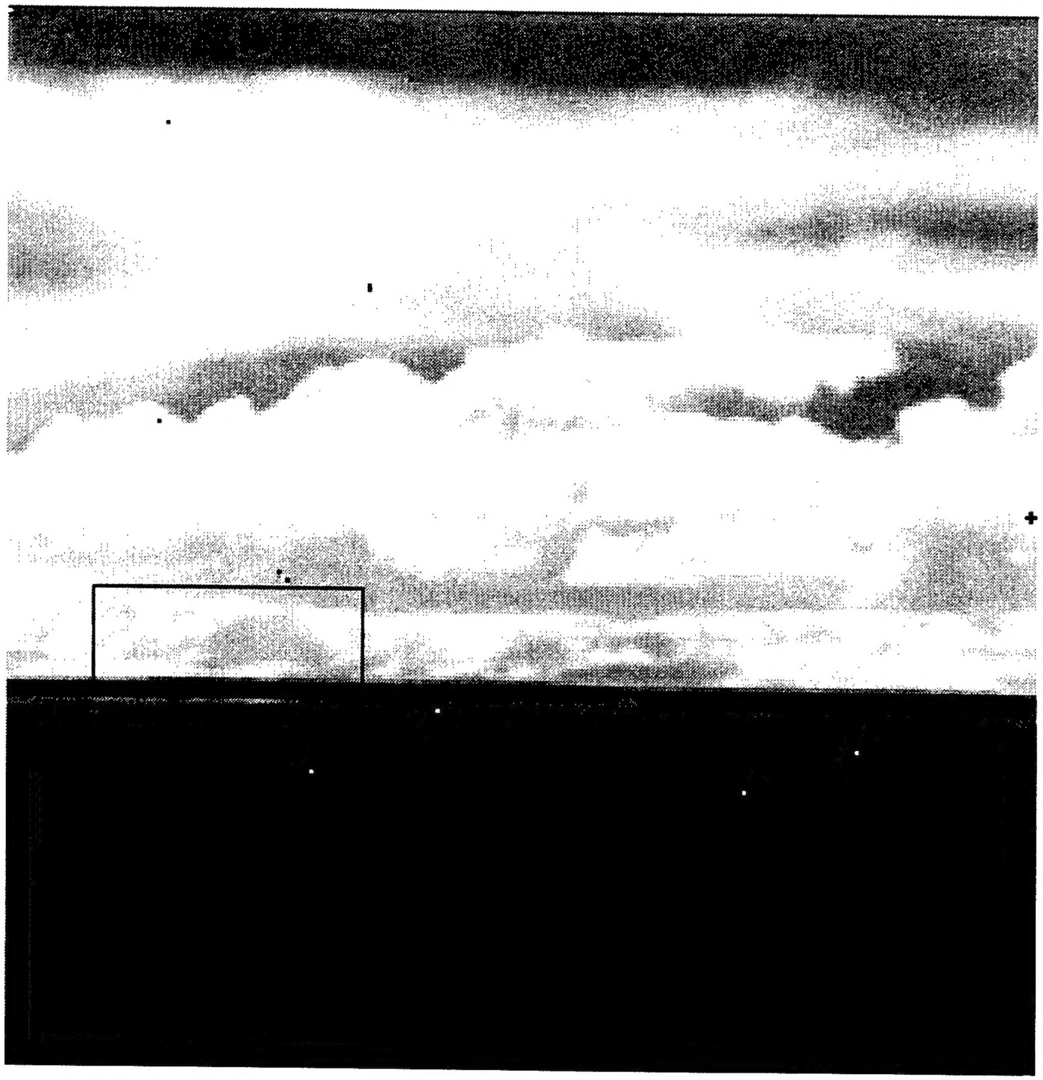

Figure 2. Frame 1788 of Sequence 2.

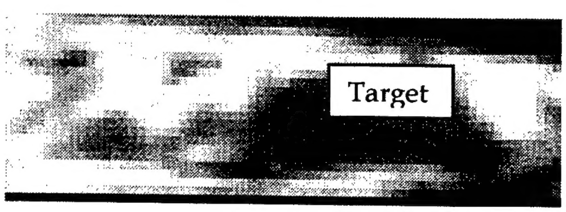

Figure 3. Frame 1788, area containing the target.

background as closely as possible in the original image without diminishing the target signal. Linear adaptive matched filters can also enhance the response to the target. The behaviour of several small support spatial filters will be analysed to determine their

positive and negative features in order to indicate their likely usefulness in various situations.

A horizontal section through the target from the last frame in the sequence of clear background images is given in Figure 4. The one pixel wide target is clearly visible. Horizontal sections through the target from the full and half resolution images of the cloud background sequence are given in Figure 5. Pixel points are not shown in the cloud sequences for clarity. The scale of the half resolution section has been expanded by a factor of 2 in this figure. The target is a single pixel in both images, and its magnitude is small. The magnitude of the half resolution target is approximately a quarter of the full resolution image, as expected. It can be seen that there is very little to distinguish the target from other peaks in the ½ scale image.

The ability of several spatial filters to highlight possible targets will be investigated. The classes of filters considered are based on morphological elements, two types of means, and medians. In this discussion only positive contrast targets will be considered, but an analogous procedure could be used for negative contrast targets.
The application of the filters will be illustrated by application to 1D sections of the half resolution of the clear background IR image shown in Figure 4 and the full resolution image section shown in Figure 5.

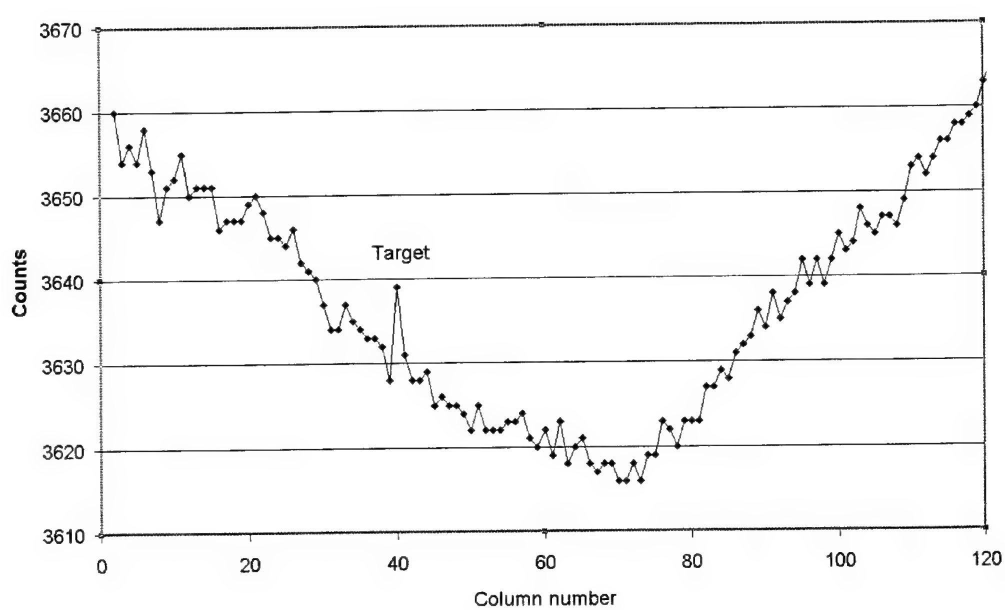

Figure 4. Row 8 of frame 1625 of clear background image sequence

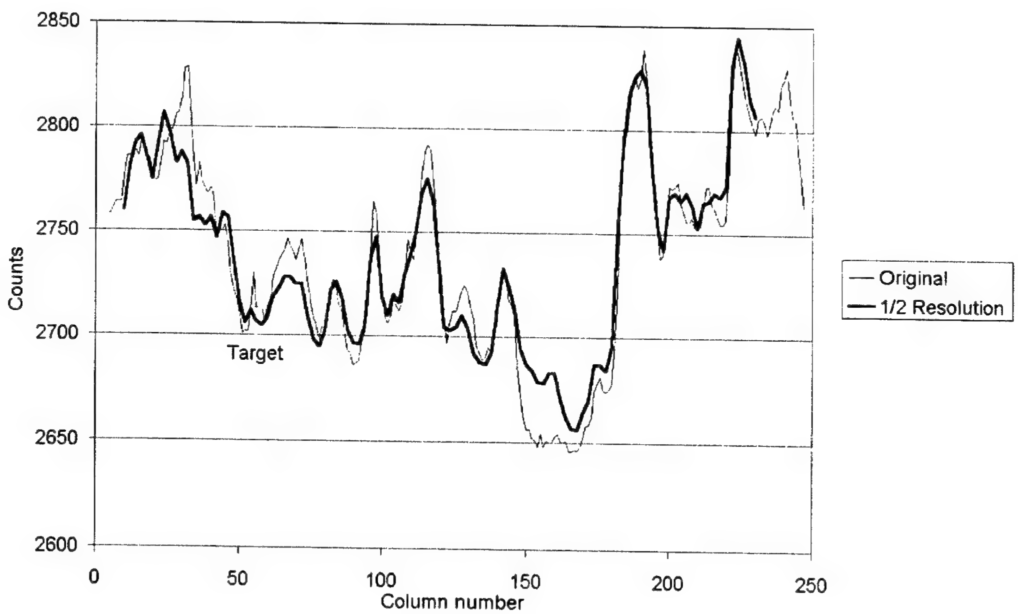

Figure 5. Row 157 of frame 1788 of cloud background image sequence

3.1 Median filters

The results of applying a 3 element linear median filter to the 1D sections of the images in Figures 4 and 5 are given in Figures 6 and 7. As expected, the median curve is

Figure 6. Original image and median of clear background scene

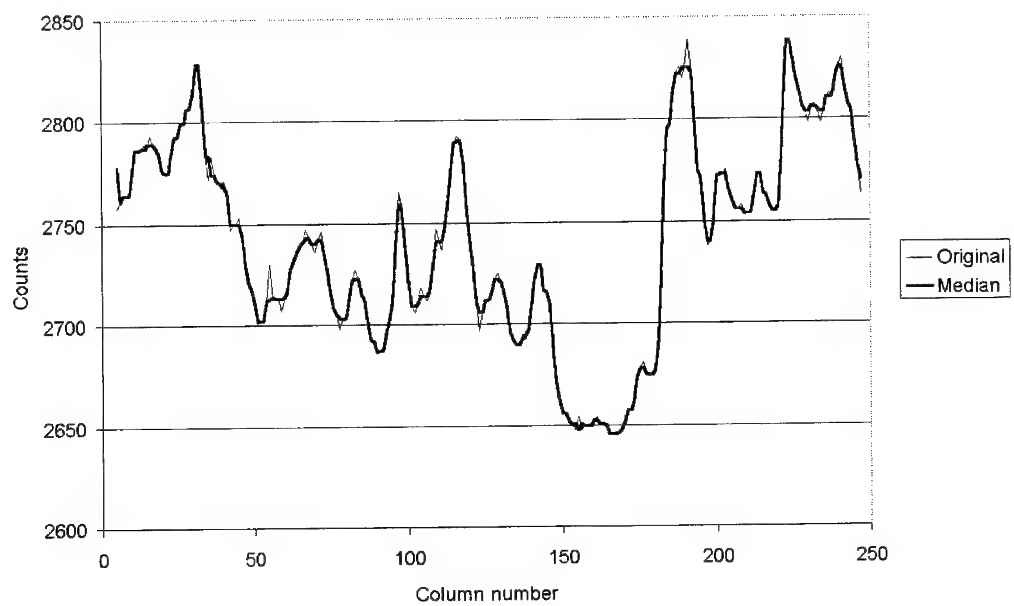

Figure 7. Original image and median of cloud background scene.

Figure 8. Original image and mean of clear background scene

intermediate between local extrema, and in the strong clutter the median overlays the image in the large slope regions. The curve of the difference between the original image and the median would consist of positive, negative and zero points, with a mean near zero.

3.2 Mean filters

The mean filter was defined as the mean of the values of the two adjacent pixels. The results of applying this filter to the clear and cloud background 1 D image sections are given in Figures 8 and 9.

The results are generally similar to those for the median filter, but there is a difference between the curves in the regions of high gradients. The mean shows both positive and negative deviations from the original curve in the high slope clutter regions, but in addition the points adjacent to peaks are also affected.

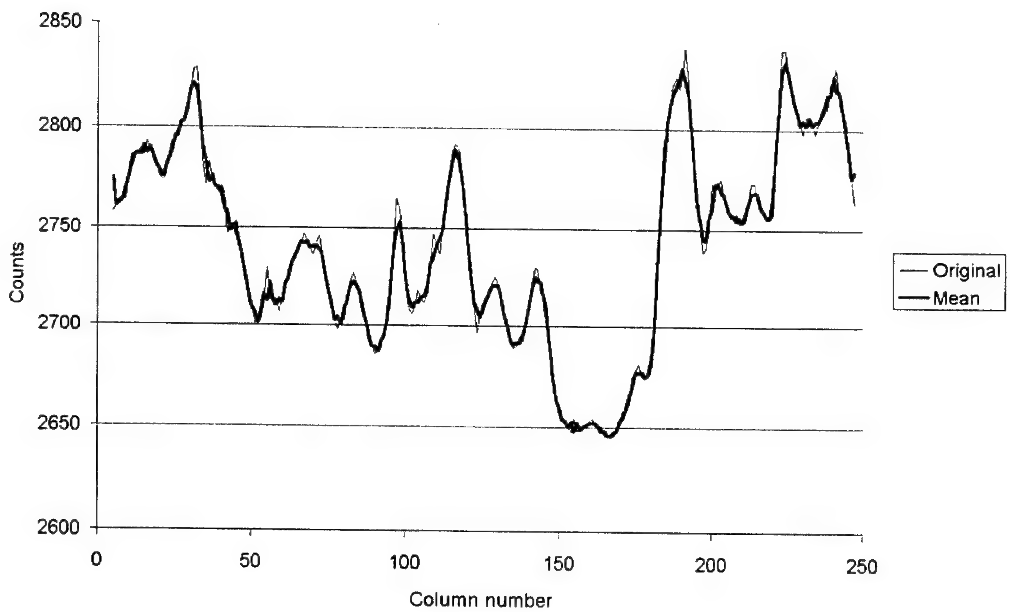

Figure 9. Original image and mean of cloud background scene.

3.3 Two element open filter

The previous filters effectively spanned a linear range of 3 pixels. A filter spanning only two pixels would be expected to follow the original curve more closely. A two pixel range filter can be defined as the opening filter, Orl2. The standard mathematical morphology open operation is defined as an erosion followed by a dilation with the reflection about the origin of the same structuring element (SE). The effect of applying

the Orl2 filter to the 1D clear and cloud image sections is illustrated in Figures 10 and 11.

Figure 10. Original image and the Orl2 filter output of clear background scene

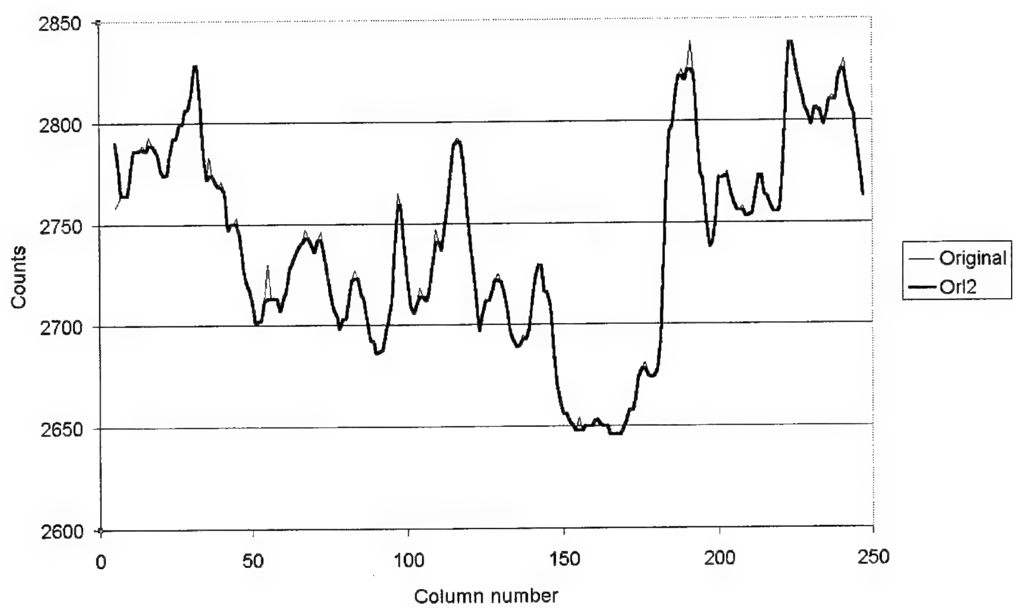

Figure 11. Original image and the Orl2 filter output of cloud background scene

The Orl2 filter highlights all the local maxima, and the output is never locally greater than the original image. The filter follows the original in the high slope regions similarly to the median filter.

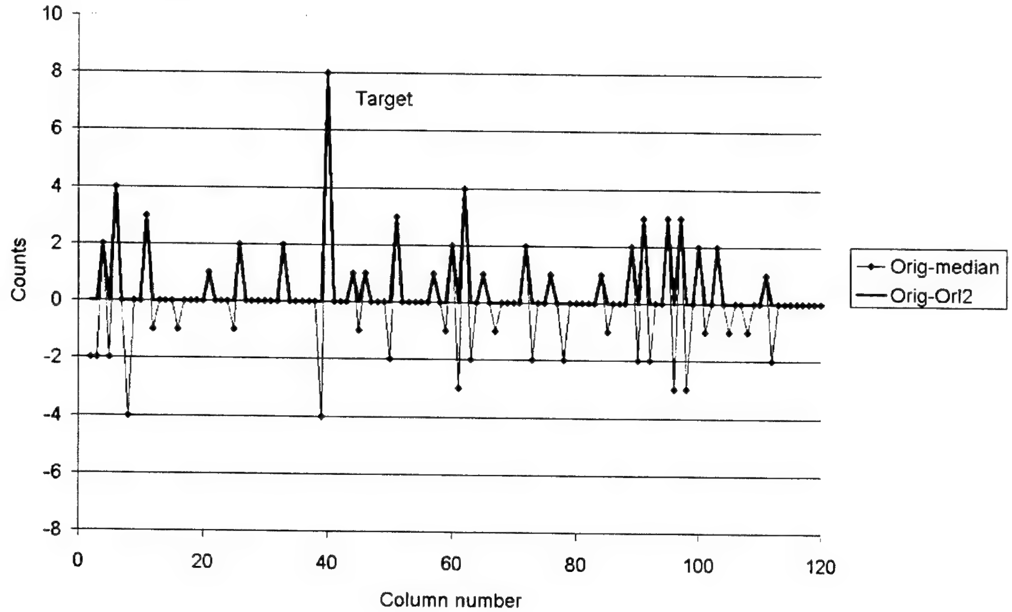

Figure 12. Difference between the original image and median and Orl2 filter outputs for the clear background

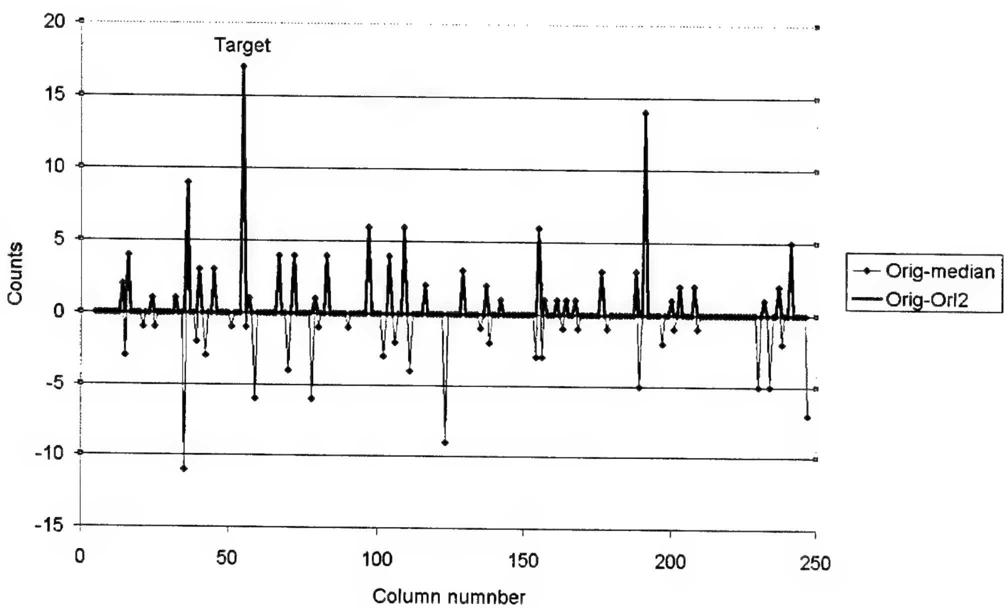

Figure 13. Difference between the original image and median and Orl2 filter outputs for the cloud background

3.4 Comparison of spatial filters

Filters for highlighting local peaks can be obtained by subtracting the filter output from the original image. The effects of subtracting the 1D median and Orl2 filters for the clear and cloud backgrounds are illustrated in Figures 12 and 13.

The target peak in the clear background section is well highlighted by both filters, but the target peak in the cloud background section is only slightly more prominent than other peaks not due to the target.

The non-negative output from both filters is identical for both backgrounds, but the median filter also gave a negative output. Note that the scale for the clear background is more expanded than the cloud background. The computational load of the Orl2 filter is less than that of the median filter, so where only the positive output is required, the Orl2 filter is to be preferred. The filter process can be inverted for negative contrast only situations.

There are regions of zero output for both filters, but they are longer in the cloud clutter image, and they usually correspond to high slope regions in the original image. This observation has important implications for the use of median filters in the detection of ultra-dim targets. If a target occurs in a high slope region, a median filter will not highlight it unless the pixel value is the maximum in the range of the median filter. This means that ultra-dim targets could be missed in strong, spatially rapidly varying clutter. The mean filter does not suffer from this drawback.

The effects of subtraction by the mean and Orl2 filters are shown in Figures 14 and 15. The target peak in the clear background section is well highlighted by both filters, but the target peak in the cloud background section is lost in a large number of peaks in the mean filter output. The positive parts are very similar for the clear background case because the background has no high slope regions. However, in the cluttered case the mean filter highlights many more positive peaks. This filter would be more effective in highlighting targets in high slope regions. However, where there is significant curvature in the background the mean filter would give peaks proportional to the amount of curvature. If the background did not vary in time these peaks would appear as false targets. The mean filter would be more effective at highlighting targets, but at the expense of a very much larger number of false alarms. This number of false alarms may overwhelm any practical tracking system.

In the benign clear background case the small support spatial filters gave good discrimination between the target pixels and the background, even though the targets were ultra-dim. However, in strong clutter backgrounds none of the filters alone is capable of reliably detecting ultra-dim targets. In addition, since a real target may appear anywhere in the image, it might not necessarily produce a peak, and hence would not be highlighted by a spatial filter. For example, a target may appear in the bottom of a trough in the brightness curve, which would only have the effect of

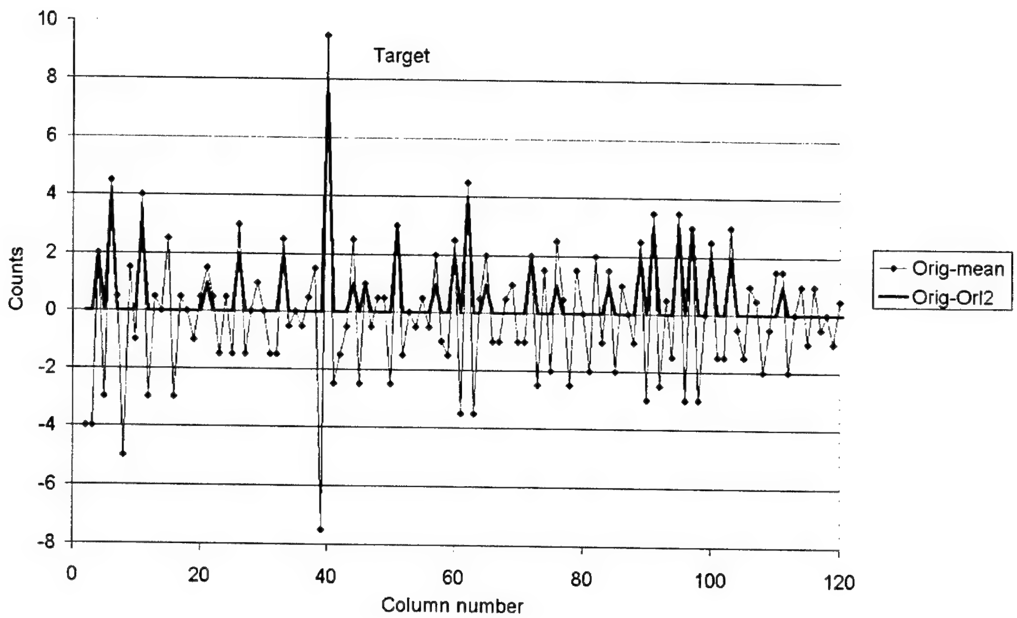

Figure 14. Difference between the original image and mean and Orl2 filter outputs for the clear background.

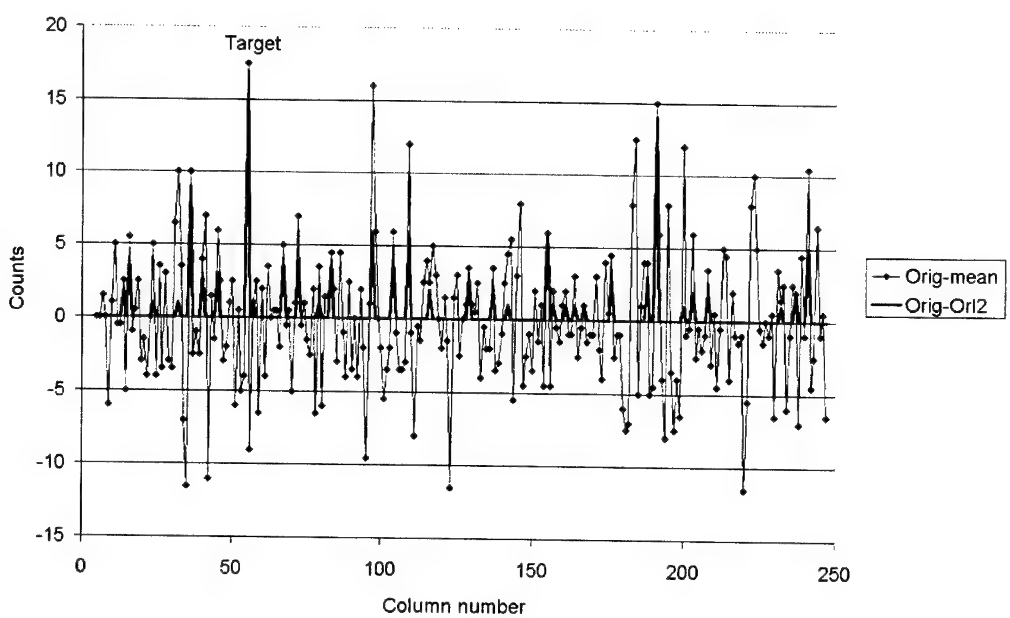

Figure 15. Difference between the original image and mean and Orl2 filter outputs for the cloud background.

reducing the depth of the trough and not appearing as a peak. Even if the target produced a peak, there is no way of determining if the peak is due to a target or clutter. Another serious problem is that for all filters in the cloud backgrounds there are many false detections, particularly for the mean filter.

These considerations show that for the case of targets in benign backgrounds the morphological and mean filters may give acceptable performance. However, spatial filters alone cannot be used for reliable detection of ultra-dim targets. However, they may be useful in combination with other types of filters. This aspect will be examined in Section 5.

3.5 2D implementation

The discussion so far has only considered 1D filters, but most image processing is 2 dimensional. Median filtering in 1D is well understood, but the generalisation to 2D is not straight forward. Arce and McLoughlin [13] showed that the median filter based on the standard square window, which is often used, gave a greater loss of resolution of small features in an image than the max/median filter. The max/median filter is defined as the maximum of a series of linear median filters through the point of interest. This means that the max/median filter follows the original image more closely than the square window median, and when subtracted from the original image the result would reduce the positive noise which would have to be considered as possible point targets.

A mean filter for the 2D case could be defined as the mean value of the surrounding 8 pixels for each pixel. However, a filter which would give a closer fit to the original image would be the max/mean filter. The max/mean filter is defined in an analogous way to the max/median filter, as the maximum of a series of linear mean filters through the point of interest. In the1D case the average of the output of the mean filter for the clear background case will be zero. In the 2D case where the max/mean filter is used, the output would be biased in the positive direction, and the average of the output would be greater than zero.

Max/mean and max/median filters have been used by Deshpande et al [12] for moving point target detection.

A max/Orl2 filter for 2D can be defined analogously to the max/median filter.

Examples of the application of max/median, max/opening and max/mean filters will be given in Section 5, where combined spatial and temporal filtering will be discussed.

4. Performance of Temporal Filters

4.1 Deviation from temporal mean

One possible way of detecting a target is to record when the temporal behaviour of a pixel begins to deviate from that of its neighbours. There are a number of factors affecting pixel brightness that are not due to targets which must be allowed for if this approach is used. Change in ambient lighting, ie the sun coming out, or drift in sensor electronics are possibilities.

The Sequence 1 dataset will be used to illustrate the effect of some temporal filters. The background above the horizon consists of very diffuse high level clouds, which are essentially featureless, Figure 1. There is no target motion so each pixel operates as a separate sensor. The target appears at pixel 40,8, and pixels at 45,8 and 60,12 will be used to indicate the background. The brightness values of the pixels in the sequence are given in Figure 16.

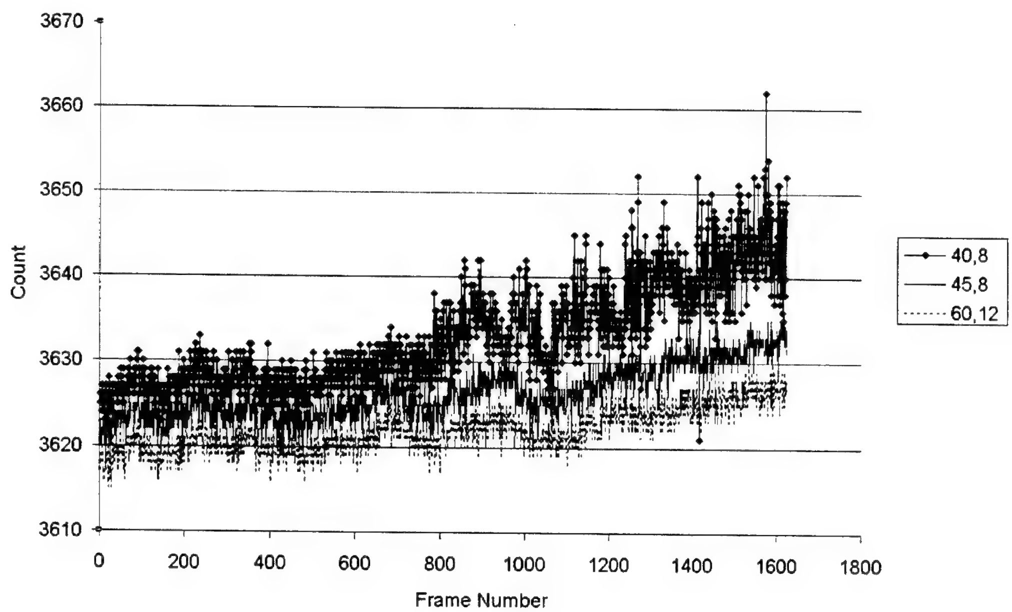

Figure 16. Pixel values of target, (40,8); and background pixels

It can be seen that after about frame 800 all signals start to increase, but the target increases more rapidly. The reason for the increase in the background is not known, it may be the sun coming from behind a cloud. The greater scatter of the target intensity is due to scintillation.

One possible way to detect the appearance of the target would be to calculate the deviations from a temporal running average and declare a target when the signals are above a threshold value from the average. For ease of computation a running average defined below will be used.

$$M(k)=\frac{(M(k-1)*(F-1))+C}{F}$$

where M(k) is the pixel mean at frame k, F is the effective number of frames included in the mean, and C is the current pixel value.

Plots of deviation of the current target value from the current mean are given in Figures 17a-17c. It can be seen that the trend of the deviation from the mean is zero, independent of the number of effective values in the mean. The same plots for the background are given in Figures 18a-18c.

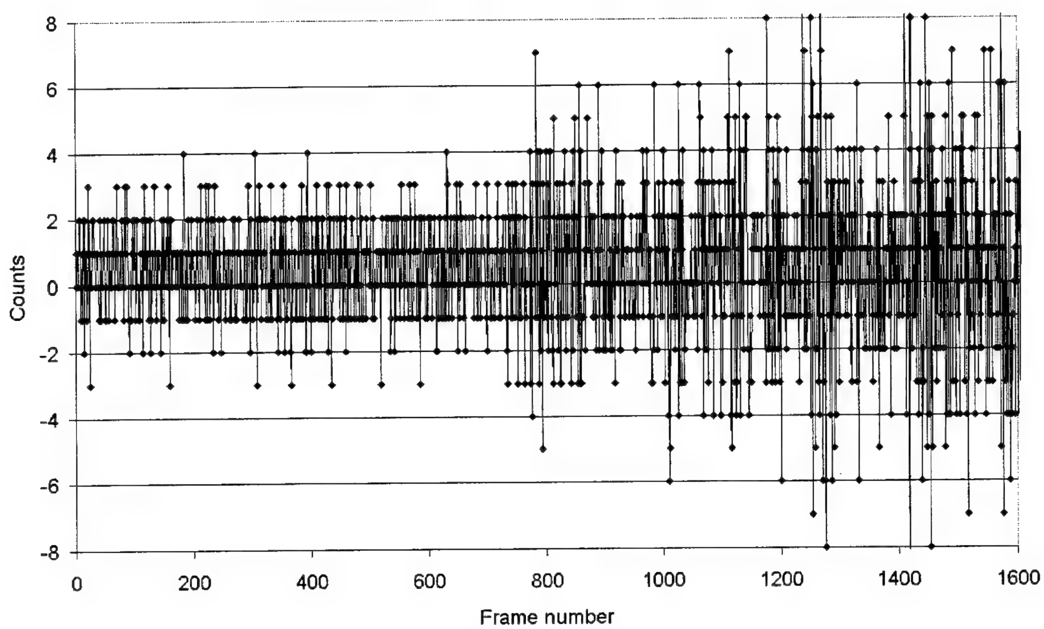

Figure 17a. Deviation of target pixel value from running mean averaged over 4 frames.

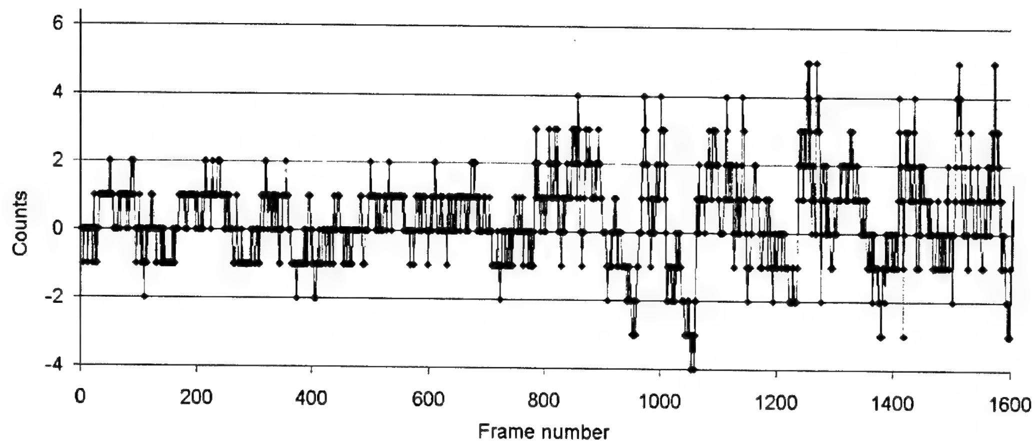

Figure 17b. Deviation of target pixel value from running mean averaged over 32 frames.

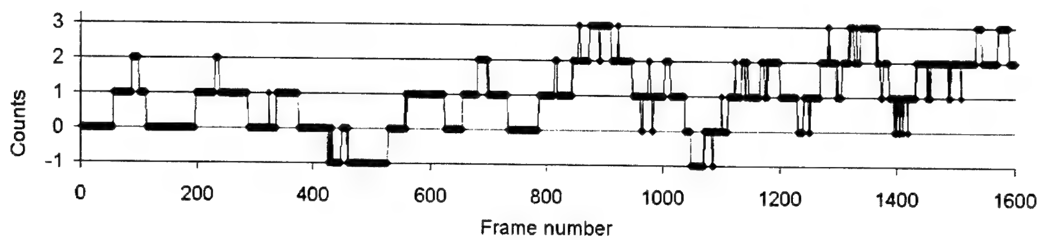

Figure 17c. Deviation of target pixel value from running mean averaged over 128 frames.

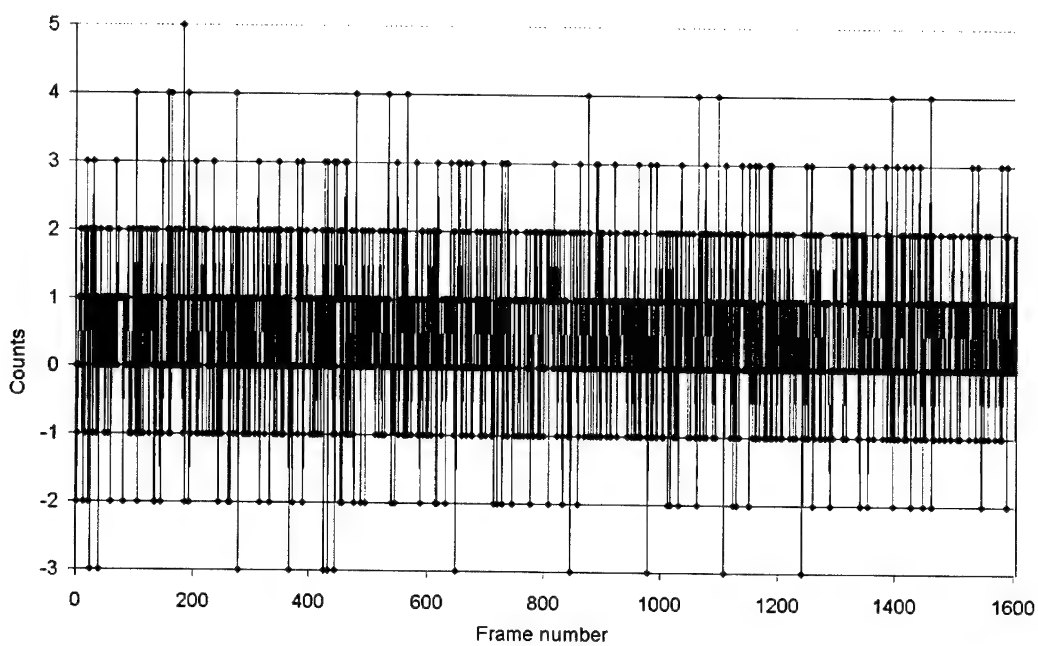

Figure 18a. Deviation of background pixel value from running mean averaged over 4 frames.

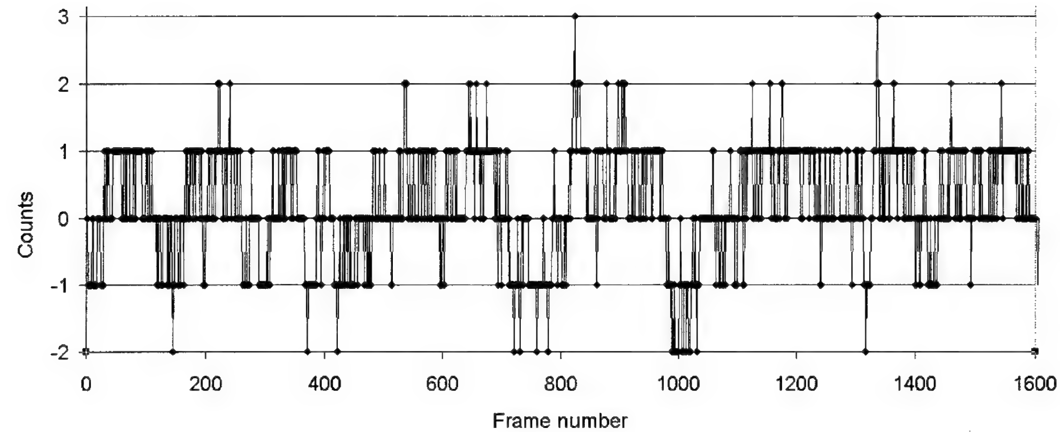

Figure 18b. Deviation of background pixel value from running mean averaged over 32 frames.

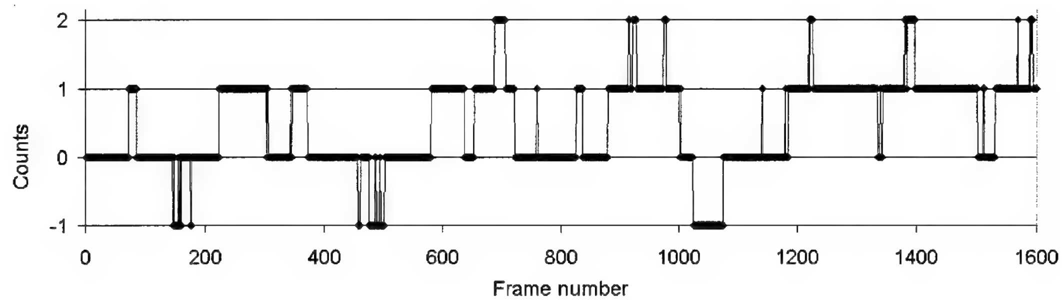

Figure 18c. Deviation of background pixel value from running mean averaged over 128 frames.

The deviations from the mean for the background pixel show constant scatter over the whole range of frames, but the deviations for the target pixel show increasing scatter when the target is present. In both cases the average deviation is approximately zero.

Hence long term deviations in pixel intensity from a running mean over time cannot be used to detect ultra-dim targets, but it may be possible to use the short term scatter. This possibility will not be considered here.

4.2 Target scintillation

In most cases the target will be scintillating and the background will be approximately constant in time. Hence the difference in temporal behaviour of the target and background could be used for target detection. The temporal variation of the image can be quantified by taking the absolute values of differences of corresponding pixel values in consecutive frames. A plot of absolute frame differences for the target and background pixels from the Sequence 1 dataset is given in Figure 19. The values were averaged with a running mean of 32 frames to increase clarity of the figure.

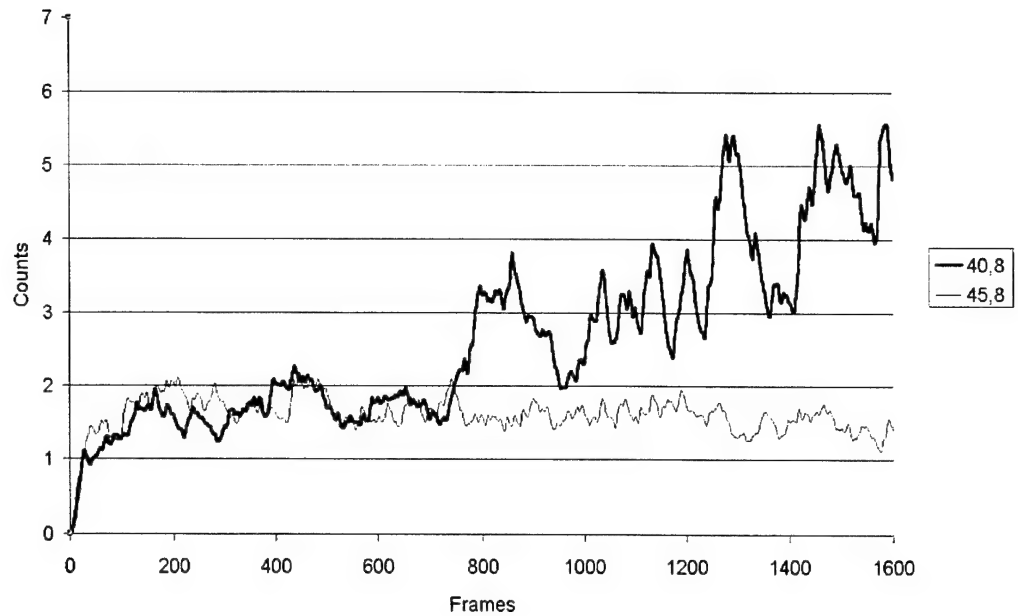

Figure 19. Absolute frame differences averaged over 32 frames, target pixel - (40,8) and background (45,8)

It can be seen that the difference is about 1 count at frame 800, and up to 3 counts at the end of the sequence. This difference should be sufficient to enable detection.

Before testing this method on the full frame Sequence 1 data, a complication to the method in cluttered scenes will be discussed in the next section.

5. Combined Temporal and Spatial Filtering

If the frames in an image sequence are highly accurately registered then taking the absolute value of frame differences alone would provide a possible method of detection of scintillating targets. However, the sensor is likely to be subjected to a variety of motions including random vibrations and platform motion. The stabilisation is unlikely to be perfect and some image movement would occur between frames. When taking frame differences this would cause a non-zero response to occur in regions of high brightness slope. These responses could appear as false targets.

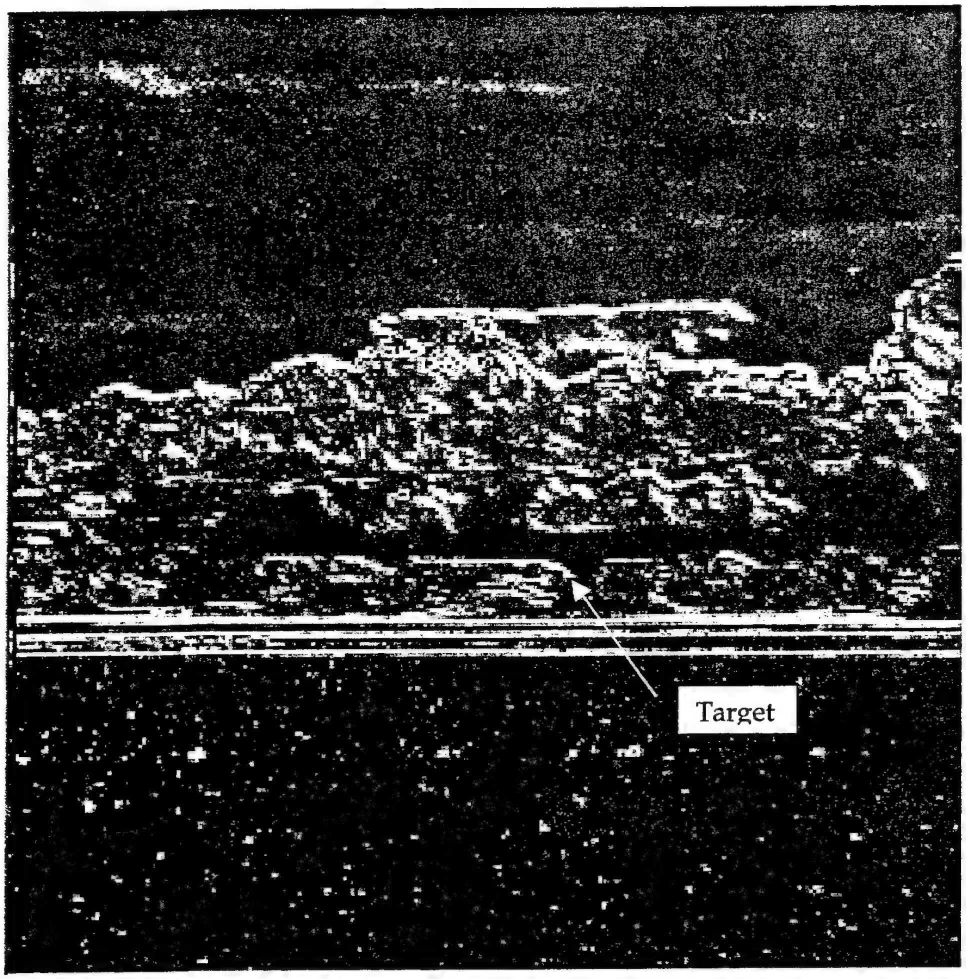

Figure 20. Frame 42 of absolute frame differencing of Sequence 2.

The effect of image motion on the absolute frame difference (AFD) of an image sequence is illustrated in Figure 20. This figure is frame 42 of the AFD of the Sequence 2 data, and is a result of a wind gust disturbing the camera. It is an example of large subpixel misregistration. Subpixel motions only need be considered as other methods can be used to register to a resolution of 1 pixel. The resolution of this image is 0.1 mrad. It can be seen that large areas of the image have significant values, even near the horizon. The pixel value due to the target is 99, and maximum value in the frame is 256 due to a sun glint on the ocean. The maximum value in the clouds is 65. This clutter must be suppressed to allow the target to be detected.

The spatial variation of the frame differences of the background is correlated, since the image moves as a whole. Advantage can be taken of this fact, and also the fact that the temporal variations of target scintillations and background are temporally

uncorrelated. The spatial correlation only extends to adjacent pixels so an opening operation with a 2 element structuring element aligned in the direction of motion should closely follow the intensity distribution of the blurring caused by the motion. Subtraction of the AFD operated on by a max/opening filter from the original AFD should remove most of the effect of motion, and leave the single point, scintillating, target. The Orl2 filter applied the frame 42 of the AFD sequence is given in Figure 21, which shows a considerable decrease in clutter from Figure 20. The effect of a max/mean subtraction filter on the AFD is given in Figure 22, which shows the non-negative values in the frame. It can be seen that there is a considerable reduction in the magnitude of the clutter in this case as well.

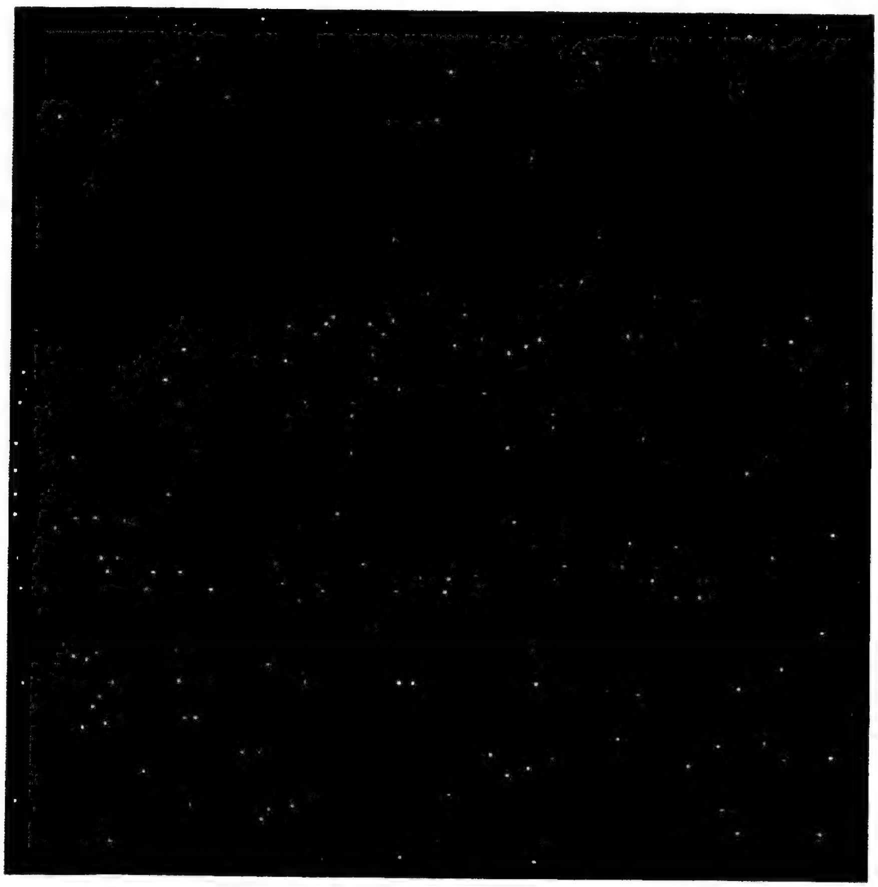

Figure 21. Orl2 filter output subtracted from the absolute frame difference of frame 42 of Sequence 2.

To compare the action of the different filters on the clutter, plots of the filter output along row 96 of the frames are given in Figures 23-24. This row includes many cloud edges, and illustrates the possible severity of the effect of sensor motion.

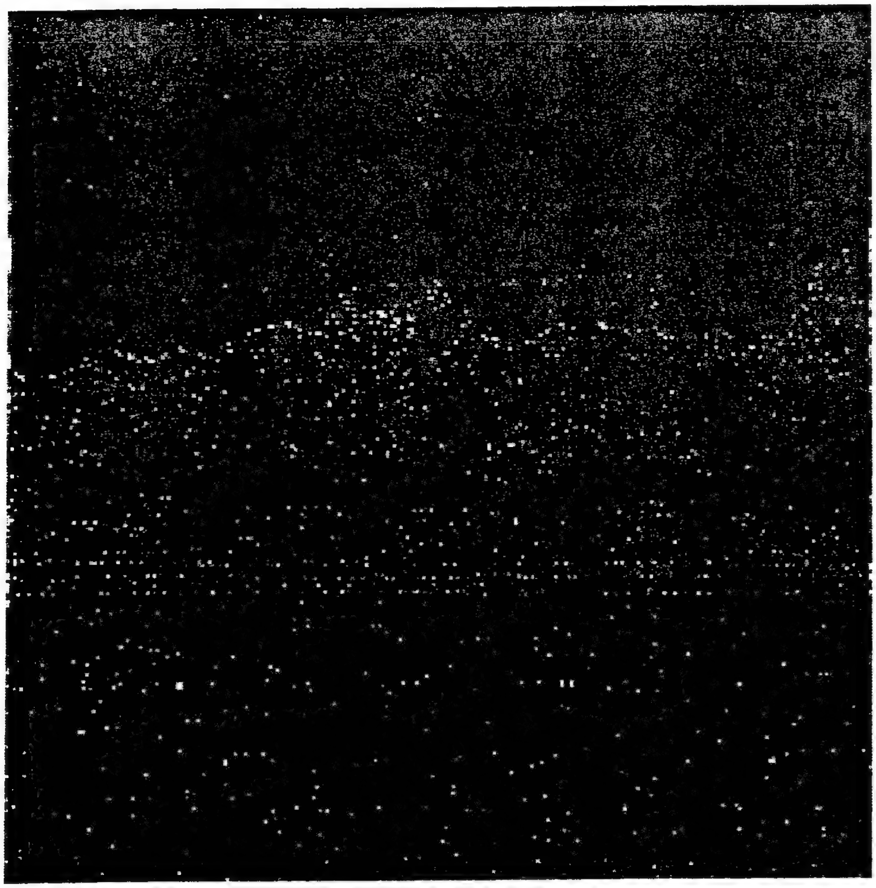

Figure 22. Max/mean filter output subtracted from the absolute frame difference of frame 42 of Sequence 2.

The curve for the AFD in the figures shows only small values for the first 60 columns, then large differences for the rest of the row, as would be expected from the image frame, Figure 20. The target value for the AFD frame is 99, and for the Orl2 frame is 9. The max/Orl2 curve follows the AFD curve in the cloud free area, but for the rest of the row it shows only a few small positive peaks, with many zero values.

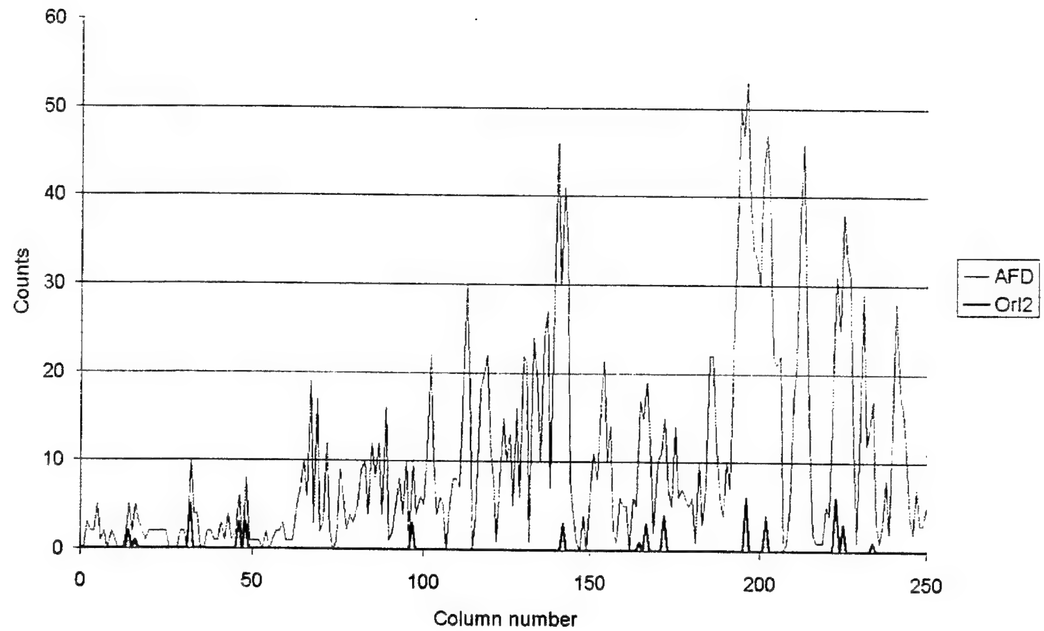

Figure 23. Pixel values along row 96 of frame 42 of Sequence 2. Absolute frame difference (AFD) and Orl2 subtraction filter.

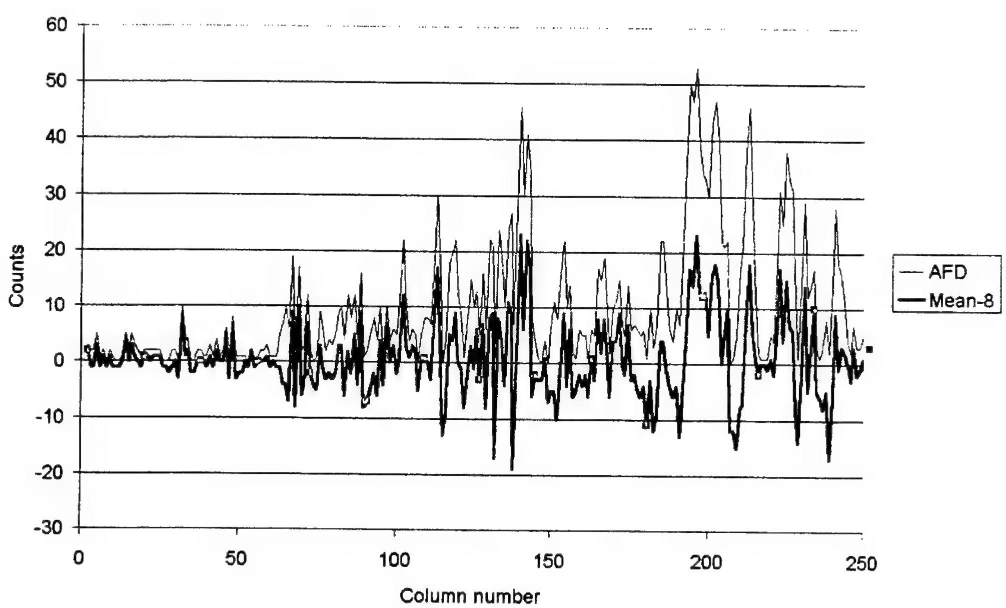

Figure 24. Pixel values along row 96 of frame 42 of Sequence 2. Absolute frame difference (AFD) and mean subtraction filter.

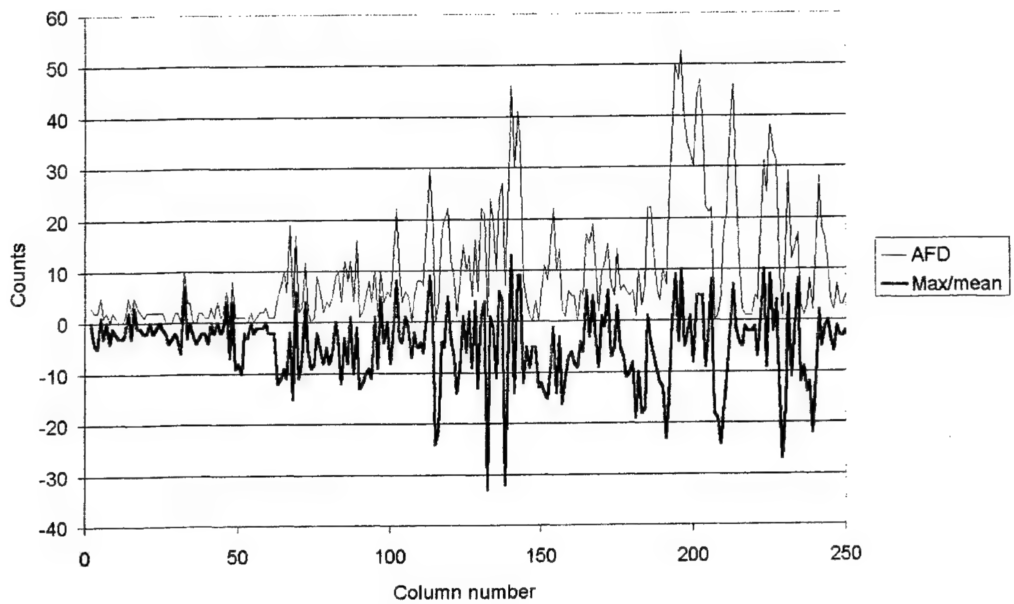

Figure 25. Pixel values along row 96 of frame 42 of Sequence 2. Absolute frame difference (AFD) and max/mean subtraction filter.

The curve for the mean-8 subtraction filter, where the mean is taken from the 8 surrounding values, is given in Figure 24. It follows the AFD curve for the first 60 columns, and then shows a similar response, but with values about half the AFD values. This would not appear to give sufficient reduction in clutter, and this is confirmed by observation of the filtered image sequence.

The max/mean filter gives a significant reduction in response to the clutter, Figure 25. There is a much reduced number of positive values and these are much lower than the AFD frame. The target value for the filtered output in this frame is 52, which is half the AFD value. Hence the max/mean filter appears to be suitable for increasing the detectability of scintillating targets.

The relative efficiency of the max/mean and Orl2 filters in reducing the motion induced clutter of the AFD sequence was measured over 2 short sequences. The first sequence was frames 41-51, where the target was relatively bright, and the second frames 1360-1380, where the target was more difficult to detect. For each sequence the average value of the target pixel was determined, and the clutter was measured both by the average number of non-zero pixels, and by the average value of the clutter pixels. The results are given in Table 1. Both filters reduced the average target value by approximately half, but the clutter measures were reduced by a much greater factor, which considerable increased the signal to clutter ratio. A measure of the signal-to-clutter ratio (SCR) can be defined as the ratio of the target signal to average clutter pixel value. Table 2 gives SCR values for the AFD and the filter outputs, and the SCR gain

for the filters. It can be seen that both filters produce a considerable increase in SCR, with a greater increase of a factor of about 6 being produced by the Orl2 filter.

Table 1. Performance of max/mean and Orl2 subtraction filters for clutter reduction of absolute frame difference (AFD) images.

	Target value	Number of active pixels	Average pixel value
Frames 41-51			
AFD	87.50	56565	3.19
Orl2	33.36	4940	0.18
Max/mean	39.90	12015	0.48
Ratio Orl2:Max/mean	0.84	0.41	0.39
Frames 1360-1380			
AFD	30.29	55234	2.43
Orl2	12.95	5056	0.18
Max/mean	19.29	11736	0.42
Ratio Orl2:Max/mean	0.67	0.43	0.42

Table 2. Signal-to-clutter ratio and signal-to-clutter ratio gain from max/mean and Orl2 filters

	SCR	SCR gain
Frames 41-51		
Abs	27.4	
Orl2	185.3	6.8
Max/mean	83.1	3.0
Ratio Orl2:Max/mean	2.2	
Frames 1360-1380		
Abs	12.5	
Orl2	71.9	5.8
Max/mean	45.9	3.7
Ratio Orl2:Max/mean	1.6	

A more detailed study with synthetic data is required to fully quantify the effect of the filters and determine their suitability for ultra-dim target detection.

6. A Test of Detection by Frame Differencing and Max/Mean Filtering

A test of the ability of the combined spatial and temporal filters to detect an ultra-dim was carried out using the Sequence 1 data. Since the target in Sequence 2 was not stationary or of constant strength, it was not possible to determine the target statistics in that sequence. However, Sequence 1 provided a known target and constant background.

Because the target is scintillating, a detector based on a simple threshold is likely to perform poorly. To take account of the scintillation, the Bayesian track before detect algorithm from [1] was used as the target detector. In order to calculate a likelihood ratio, the distribution function of the background values has to be known, and the process is much simpler if that function is a Gaussian. An estimate of the background statistics was obtained from the values of pixel (128,4) over the whole sequence, which appears to be clear sky. The histograms of the AFD and filtered values for the whole sequence are given in Figure 26. The AFD values are all non-negative, by definition, and the histogram peaks at 1 count. The Orl2 curve is very asymmetrical and peaks at zero as expected from Figure 23, (the zero value is suppressed because it is far off scale). The mean curves are more symmetrical and bell shaped. A fair fit to a Gaussian curve was obtained for the max/mean curve. The mean was -1.41 and the standard deviation was 1.89, with a correlation coefficient of 0.991

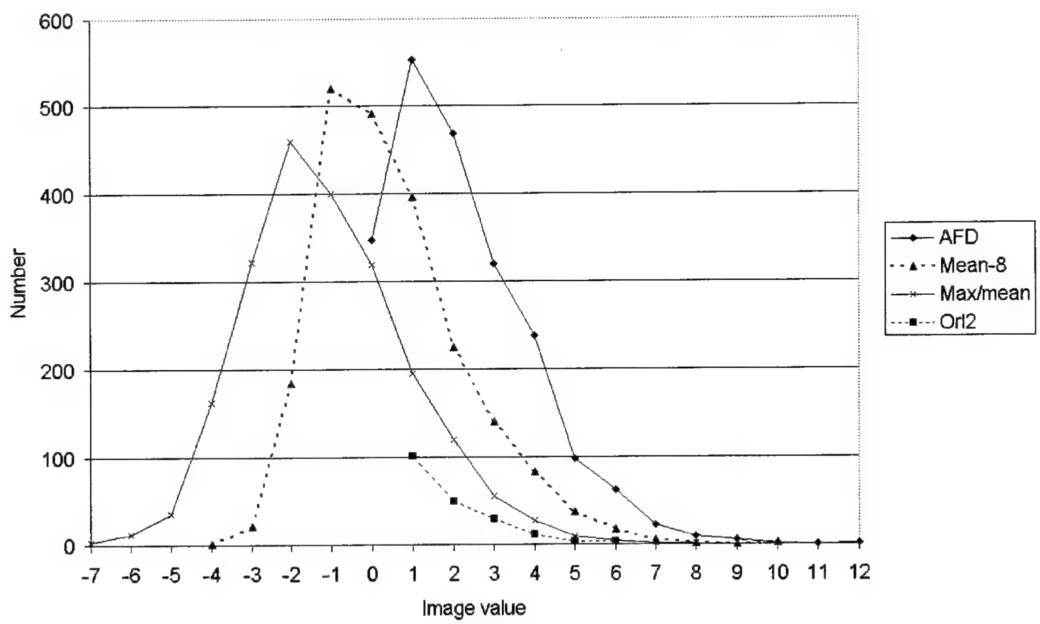

Figure 26. Histograms of values of pixel 128,4 of Sequence 2 for the absolute frame difference, and filters Orl2, mean and max/mean.

The output of the absolute frame differencing followed by the max/mean filter for the target pixel is given in Figure 27. There are areas of increased value after frame 750 when the target is present. The filtering produced very little change in the values from the AFD values. There is a small but significant increase in filter output at the target position when the target appears, but the difference is so small that the extra sensitivity of the Bayesian algorithm is required to reliably detect it. The algorithm was set up for the max/mean filter because the background statistics were Gaussian, which gave a simple log likelihood ratio.

The result of the detection algorithm is illustrated in Figure 28. The curve plots the output value for the target pixel. Any value above zero corresponds to a detection. It can be seen that the target is detected for most of the time it is present, but the number of detections is less than for the direct detection from the original image [1]. This is to be expected as some information is lost by the extra clutter minimisation procedures. There were some false alarms, caused mainly by birds. Optimisation of the parameters in the algorithm would probably reduce the false alarm rate.

Because of the loss of information in the calculating the AFD and applying the temporal/spatial filtering, this procedure would not be the most effective detection algorithm for bright targets or benign backgrounds. In practice it would be necessary to segment an image and apply the AFD and temporal/spatial filter to cluttered regions, and more standard spatial and/or temporal filters to uncluttered regions.

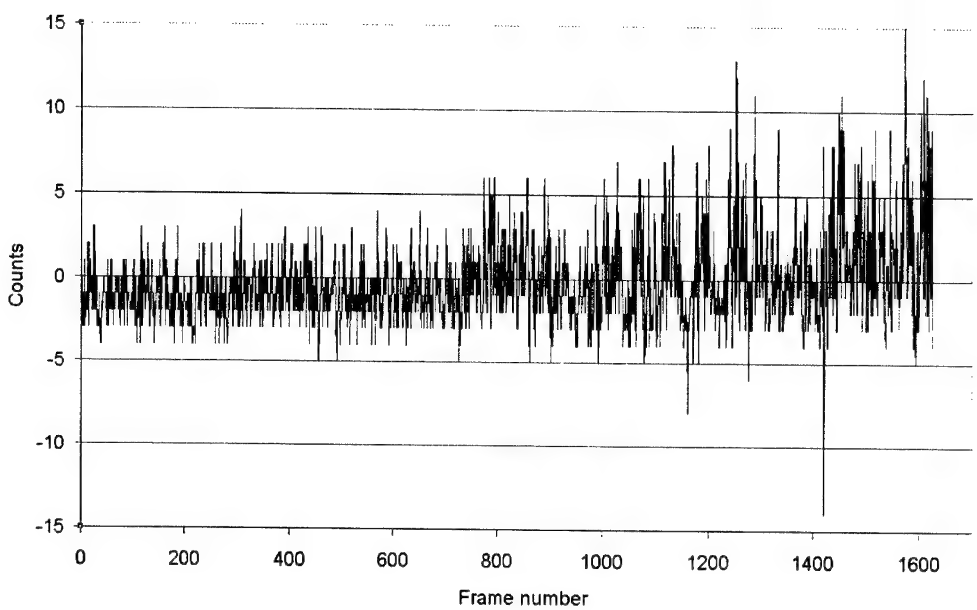

Figure 27. Output of frame differencing plus max/mean filter for the target pixel 40,8 for the Sequence 1 data.

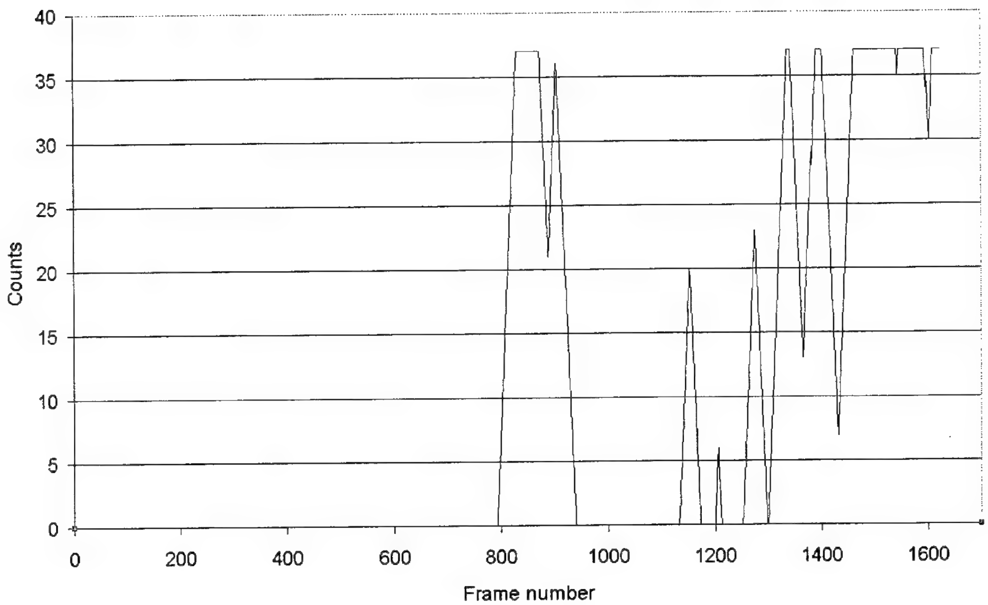

Figure 28. Output from detection algorithm for target pixel 40,8.

Further work is required to determine the range of conditions over which the temporal/spatial filter gives better results than standard filters.

7. Conclusions

The effectiveness of small support spatial filters based on mean, median and morphological opening for the detection of scintillating ultra-dim stationary point targets in IR image sequences has been investigated. The effectiveness of two temporal filters was also studied. It was demonstrated that spatial or temporal filters used separately are not effective for the detection of these targets in heavy clutter in IR image sequences, but the spatial filters perform adequately for benign clutter.

For image sequences at video frame rates a detection algorithm based on taking absolute frame differences followed by small support spatial filter can give a significant increase in signal to clutter ratio of scintillating targets in heavy clutter.

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R.C. Warren

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19. ABSTRACT

The effectiveness of small support spatial filters based on mean, median and morphological opening for the detection of scintillating ultra-dim stationary point targets in IR image sequences has been investigated. The effectiveness of two temporal filters was also studied. The filters were applied to two IR image sequences; an aircraft approaching in an uncluttered background, and an aircraft receding in a bright cloudy background. The spatial filters were effective in detecting the target in the benign background, but neither the spatial nor one of the temporal filters were effective in the cluttered environment. A combination of absolute frame differencing and small support spatial filtering to correct for sensor motion was found to give sufficient increase in signal to clutter ratio to allow detection.

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